MR Imaging of Atherosclerotic Plaques

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MRI for Carotid Atheroma

- Excellent tissue contrast (fat, fibrous tissue, collagen, thrombus)
- Noninvasive
- More accurate and objective estimation of stenosis degree than US
Carotid MRI at 1.5T

- Experiences for a decade
- MRI has shown capability to detect vulnerable plaques with large lipid/necrotic cores, intraplaque hemorrhage and plaque cap rupture.
- 3.0 T MRI is expected to show higher resolution enough for smaller arteries.
SENS-Flex-M Coil
## MRI Appearance of Plaque Components on Various Imaging Sequences

<table>
<thead>
<tr>
<th>Plaque Components</th>
<th>T2WI</th>
<th>T1WI</th>
<th>T1WI, Fat-Suppr.</th>
<th>Proton WI</th>
<th>TOF</th>
<th>CE on Post-Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent Hemorrhage</td>
<td>Variable</td>
<td>H-to-M</td>
<td>H</td>
<td>Variable</td>
<td>H</td>
<td>No</td>
</tr>
<tr>
<td>Lipid-rich Necrotic Core</td>
<td>Variable (L)</td>
<td>H</td>
<td>M-to-H</td>
<td>H</td>
<td>M</td>
<td>No</td>
</tr>
<tr>
<td>Fibrous Tissue</td>
<td>Variable</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>M-to-L</td>
<td>Yes</td>
</tr>
<tr>
<td>Calcification</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>No</td>
</tr>
</tbody>
</table>

Tissue contrast is relative to SI of muscle
Stable Plaque

T2WI

Pathology
Fibrous Cap on MRI
Fresh Intraplaque Hemorrhage with Fibrous Cap Rupture

Fresh hemorrhage

Cap rupture

TOF
Intact Plaque Cap with Intraplaque Hemorrhage (fibrin)

Hemorrhage in 31% of 153 endarterectomy specimens
Contrast-enhancement in Fibrous Component
• Increased neovascularity within plaque may contribute to plaque instability.
• Contrast-enhancement represents neovasculature in the histopathology (sensitivity 76%, specificity 79% by Yuan).
• Contrast-enhancement improves differentiation of tissue types (fibrous tissue, necrotic core, calcifications).
Large Necrotic Core without Significant Contrast Enhancement
Hydrophilic Necrosis

T1WI  T2WI  Specimen
MRI Accuracy

- Ex vivo T2WI: Accurate for fibrocalcific plaques (90% sensitivity, 100% specificity) - Serfaty et al
- In vivo multispectral MRI for lipid-rich cores and intraplaque hemorrhage: overall accuracy 87%, sensitivity 85%, specificity 92% - Yuan et al
Fibrous Cap Rupture at MRI and Recent TIA or Stroke
(Yuan, Circulation 2002)

<table>
<thead>
<tr>
<th></th>
<th>% Symptomatic</th>
<th>Likelihood to have TIA/ stroke</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact thick FC (n = 11)</td>
<td>9</td>
<td>1X</td>
<td></td>
</tr>
<tr>
<td>Intact thin FC (n = 12)</td>
<td>50</td>
<td>10X (95% CI = 1.0, 104)</td>
<td>6</td>
</tr>
<tr>
<td>Ruptured FC (n = 30)</td>
<td>70</td>
<td>23X (95% CI = 3, 210)</td>
<td>18</td>
</tr>
</tbody>
</table>
Brain MR imaging in Pts with Unstable Carotid Plaques

• In 153 patients, carotid MRI-MRA and carotid endarterectomy were performed.
• 97 atheromas (72%): histologically unstable plaque
• Good agreement between MR imaging and histologically vulnerable plaque
• 59 (61%) showed acute ischemic lesions in the brain on diffusion MR imaging.
Case 1, Ulcerative Plaque with Hemorrhage
Multifocal Recent Infarctions on Diffusion-weighted MRI
Case 2, Hemorrhagic Plaque

TOF  T2  T1FS  T1CE
Case 3, Hemorrhagic Plaque
Multiple New Infarctions
MRA of Intraplaque Hemorrhage
Materials & Methods

• 153 consecutive patients who underwent MRI and carotid endarterectomy were included in this study.
• Performed high-resolution MR imaging before carotid surgery.
• Findings on surgery, MRI (in vivo, specimen), and pathology were correlated.
• Analysis of carotid bifurcation and proximal ICA
Results

• 42 atheromas (31%) had intraplaque hemorrhage on surgicopathological findings.
• 38 (90.5%) showed high signal intensity halo around the carotid artery on TOF MR angiography.
• Additional sequence of T1-weighted fat-saturated spin echo images also revealed evidence of intraplaque hemorrhage by showing unsaturated high signal intensity in the plaque in 71% of patients.
Results

- Correlated with surgical and histopathological findings, MIP images of TOF MR angiography demonstrated:
  - sensitivity = 91%,
  - specificity = 91%,
  - negative predictive value = 77%,
  - positive predictive value = 93%.

- The combination of high signal intensity areas on T1-WI with fat suppression, low signal intensity areas on T2-WI, and high SI areas on source images of the 3D time-of-flight MRA sequence also can suggest intraplaque hemorrhage.
Conclusions

• High-resolution MR imaging can help identify intraplaque hemorrhage noninvasively.

• High SI on source images of 3D-TOF MRA and fat-suppressed T1WI can suggest intraplaque hemorrhage.

• Maximum intensity projection images of TOF MR angiography are useful in noninvasive detection of carotid intraplaque hemorrhage.
Changes in Carotid Plaques after Statin Therapy: MRI Evaluation

- 45 pts with 30-70% stenosis
- PreTx (Simbastatin 20 mg) and F-up MRI (19 ± 7.5 m)
- Decreased mean total chol., LDL, & CRP compared with control group:
  Total Chol = 188 ± 26 vs 158 ± 50, p<0.001
  LDL = 125 ± 23 vs 110± 42, p <0.01
  CRP =0.41 ± 0.59 vs 0.10 ± 1.3, p<0.01
Results

• Stabilization of plaque components on MRI in 16% (7/45)
• Decreased plaque thickness:
  4.2 mm± 1.0 vs 3.4 mm ± 1.3, p < 0.001
Increased Fibrotic Component on T2WI at 20 m f-up
Improved Wall Thickness, at 1 y (0.5 mm)
3.0 T for Atherosclerotic Plaque Imaging

- Higher signal-to-noise ratio
- Better background suppression
- Shorter scan time
- Higher resolution
Carotid MRI Techniques at 3.0 T

- T1-weighed spin echo imaging (precontrast axial, again with fat-saturation, postcontrast axial)
- T2-weighted spin echo imaging (axial)
- Proton-WI (axial)
- 3D time-of-flight MRA (source and 3D images)
- Two 15-cm phased-array coils, bilateral application
- Field of view: 12-15 cm x 12-15 cm
- Slice thickness = 2 mm, 256x203 matrix, NEX = 1
SMC Experience of 3.0 T MRI in Carotid Plaque Imaging

- Image quality is generally compatible with 1.5 T’s.
- Higher resolution and tissue contrast with 3.0 T MRI
R ICA Plaque, 1.5T vs 3.0T

T1WI, fat-saturation @1.5 T vs 3.0 T
MIP of 3D-TOF MRA @1.5 T vs 3.0 T
T2WI @1.5 T vs 3.0 T
Coronary Artery Plaque MRI
• High-resolution of 3.0 T system is most beneficial in coronary artery plaque imaging.

• Can knowledge of carotid plaque MRI be applied to coronary artery imaging?
Imaging Protocol

• Coronary MRA using 3-point technique
• Black-blood plaque imaging on the stenotic segments
  – T1WI, precontrast (DBIR)
  – T2WI
  – T1WI, postcontrast
  – TFE
• Slice thickness, 1.5-2 mm; image matrix, 256x256, FOV 35 cm, en = 1
Coronary Artery Plaque Imaging: LAD Stenosis on CAG
Coronary Plaque Imaging at 3.0T

T2WI  T1WI-preContrast  T1WI-postContrast
Fibrofatty Plaques
(M/48 with Acute MI)
Intravascular US Shows Noncalcified Plaques without Large Hypoechoic Area
Coronary MRA
L Main

T2WI, Fat-sat  T2WI, 1.5 mm ST  PostContrast
Contrast Agents for MR Imaging of Atherosclerosis

- Ultrasmall superparamagnetic particles of iron oxide (USPIO, Combidex ®)
- Fibrin-specific polypeptide (EPIX)
- Plaque detection by Gadofluorine (Schering)
USPIO in Watanabe Hyperlipidemic Rabbits (5 ds)

Watanabe   Control   Watanabe

USPIO      USPIO      No USPIO

Ruehm at al. Circulation 2001
Fe in Macrophages of Atheroma

Prussian Blue staining

EM
Gadofluorine M

Accumulation in
- necrotic, edematous, lipid rich areas and macrophages (?)
2 days after Gadofluorine M injection in Cholesterol-fed diabetic Rabbit, 14-T MR Microscopy vs Specimen

Courtesy of Dr Whal Lee, Seoul National University
Fibrin-specific polypeptide (20 h post EP-1873, EPIX)

Botnar, Circulation 2004
Alpha\textsubscript{v}beta\textsubscript{3}-Integrin-targeted Imaging: significances

- Plaque angiogenesis and expansion of vasa vasorum: critical process for initiation of vascular lesions
- Site-specific drug delivery for early atherosclerotic disease
Alpha<sub>v</sub>beta<sub>3</sub>-Integrin-targeted paramagnetic nanoparticles in atherosclerotic rabbits

Winter, Circulation 2003
Conclusions

• High-resolution MRI can identify vulnerable carotid plaques and allows early intervention on unstable plaques.
• 3.0 T MRI allows characterization of atherosclerotic plaques in coronary arteries.